

We claim:

1 1. An optical router for routing wavelength
2 channels received in bundles of wavelength channels, the
3 router comprising:

4 a plurality of wavelength filters, one filter of the
5 plurality of wavelength filters per bundle, each filter of
6 the plurality of wavelength filters being capable of
7 separating one or more wavelength channels from the bundle
8 associated with the filter;

9 a plurality of wavelength converters, one converter
10 of the plurality of wavelength converters per bundle, each
11 converter being capable of receiving an add wavelength
12 channel and converting the received add wavelength channel
13 to a transformed wavelength;

14 a plurality of multiplexing units, one multiplexing
15 unit of the plurality of multiplexing units per bundle,
16 each multiplexing unit of the plurality of multiplexing
17 units being capable of multiplexing at least a subset of
18 channels of the bundle associated with said each
19 multiplexing unit and the add wavelength channel converted
20 by the converter associated with the bundle that is
21 associated with said each multiplexing unit;

22 a first spatial switching fabric comprising a
23 plurality of inputs and a plurality of outputs, the inputs
24 of the first spatial switching fabric being coupled to the
25 plurality of wavelength filters to receive the separated
26 one or more wavelength channels; and

27 a plurality of channel combiners, one channel
28 combiner of the plurality of channel combiners per
29 multiplexing unit of the plurality of multiplexing units,
30 each channel combiner of the plurality of channel
31 combiners being coupled to a different one of the outputs
32 of the plurality of outputs of the first spatial switching
33 fabric, said each channel combiner being capable of
34 receiving and multiplexing channels received from the
35 corresponding output of the plurality of outputs of the
36 first spatial switching fabric and the channels
37 multiplexed by the multiplexing unit associated with said
38 each channel combiner.

1 2. An optical router according to claim 1, wherein
2 said each filter of the plurality of wavelength filters
3 comprises a tunable band pass filter capable of separating
4 different one or more wavelength channels.

1 3. An optical router according to claim 2, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a tunable pump source capable of
4 producing pump output at different wavelengths to enable
5 said each converter to convert the received add wavelength
6 channel to different transformed wavelengths.

1 4. An optical router according to claim 1, wherein
2 said each wavelength filter of the plurality of wavelength
3 filters comprises a circulator having consecutive first,
4 second, and third ports, and a Bragg grating coupled to
5 the third port of the circulator.

1 5. An optical router according to claim 4, wherein
2 the Bragg grating of said each wavelength filter is a
3 tunable Bragg grating capable of being adjusted to reflect
4 different wavelengths.

1 6. An optical router according to claim 1, wherein
2 said each wavelength filter of the plurality of wavelength
3 filters comprises:
4 a fused fiber optical power splitter comprising an
5 input path capable of receiving the bundle associated with
6 said each wavelength filter, a pass-through output path

7 for outputting at least the subset of channels of the
8 bundle associated with said each wavelength filter, and a
9 first separated output path capable of outputting the one
10 or more wavelength channels separated from the bundle
11 associated with said each wavelength filter; and

12 a first band pass filtering element coupled to the
13 first separated output path so that the one or more
14 wavelength channels separated from the bundle associated
15 with said each wavelength filter pass through the first
16 band pass filtering element, the first band pass filtering
17 element having a first passband.

1 7. An optical router according to claim 6, wherein:

2 the fused fiber optical power splitter of said each
3 wavelength filter further comprises a second separated
4 output path capable of outputting the one or more
5 wavelength channels separated from the bundle associated
6 with said each wavelength filter; and

7 said each wavelength filter further comprises a
8 second band pass filtering element coupled to the second
9 separated output path so that the one or more wavelength
10 channels separated from the bundle associated with said
11 each wavelength filter pass through the second band pass

12 filtering element, the second band pass filtering element
13 having a second passband.

1 8. An optical router according to claim 6, wherein
2 said each wavelength filter further comprises active fiber
3 filler in the first separated output path, the active
4 fiber filler being for amplifying the one or more
5 wavelength channels separated from the bundle associated
6 with said each wavelength filter.

1 9. An optical router according to claim 6, wherein
2 said each wavelength filter further comprises a pass-
3 through band reject filtering element coupled to the pass-
4 through output path for removing the one or more
5 wavelength channels separated from the bundle associated
6 with said each wavelength filter from the subset of
7 channels of the bundle associated with said each
8 wavelength filter.

1 10. An optical router according to claim 9, wherein:
2 the pass-through band reject filtering element of
3 said each wavelength filter comprises a tunable pass
4 through filtering element capable of being adjusted to
5 reject different wavelengths; and

6 the first band pass filtering element comprises a
7 first tunable filtering element capable of being adjusted
8 to transmit different wavelengths.

1 11. An optical router according to claim 1, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a difference frequency mixer.

1 12. An optical router according to claim 11,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and
6 the difference frequency mixer of said each converter
7 of the plurality of wavelength converters comprises a
8 tunable pump source capable of producing pump output at
9 different wavelengths to enable said each converter to
10 convert the received add wavelength channel to different
11 transformed wavelengths.

1 13. An optical router according to claim 1, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a cross-gain modulator.

1 14. An optical router according to claim 13,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the cross-gain modulator of said each converter of
7 the plurality of wavelength converters comprises a tunable
8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 15. An optical router according to claim 1, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a cross-phase modulator.

1 16. An optical router according to claim 13,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the cross-phase modulator of said each converter of
7 the plurality of wavelength converters comprises a tunable

8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 17. An optical router according to claim 1, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a four-wave mixer.

1 18. An optical router according to claim 13,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the four-wave mixer of said each converter of the
7 plurality of wavelength converters comprises a tunable
8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 19. An optical router according to claim 1, further
2 comprising a plurality of power equalizers, one equalizer
3 per wavelength converter of the plurality of wavelength

4 converters, each equalizer being interposed between the
5 converter associated with said each equalizer and the
6 multiplexing unit corresponding to the wavelength
7 converter associated with said each equalizer.

1 20. An optical router according to claim 1, wherein
2 said each multiplexing unit comprises a circulator.

1 21. An optical router according to claim 3, wherein
2 said each multiplexing unit comprises a circulator.

1 22. An optical router according to claim 1, wherein
2 said each multiplexing unit comprises a fused fiber
3 optical power splitter.

1 23. An optical router according to claim 3, wherein
2 said each multiplexing unit comprises a fused fiber
3 optical power splitter.

1 24. An optical router according to claim 1, further
2 comprising a second spatial switching fabric comprising a
3 plurality of inputs and a plurality of outputs, one input
4 of the plurality of inputs of the second spatial switching
5 fabric per channel combiner of the plurality of channel

6 combiners, each input of the plurality of inputs of the
7 second spatial switching fabric being coupled to the
8 channel combiner associated with said each input of the
9 plurality of inputs of the second spatial switching fabric
10 to receive the channels multiplexed by the channel
11 combiner associated with said each input of the plurality
12 of inputs of the second spatial switching fabric.

1 25. An optical router according to claim 24,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 said each converter of the plurality of wavelength
7 converters comprises a tunable pump source capable of
8 producing pump output at different wavelengths to enable
9 said each converter to convert the received add wavelength
10 channel to different transformed wavelengths.

1 26. An optical router according to claim 24, further
2 comprising:

3 a plurality of optical amplifiers, one amplifier of
4 the plurality of amplifiers per channel combiner, each

5 amplifier of the plurality of amplifiers being interposed
6 between the channel combiner associated with said each
7 amplifier and the input of the plurality of inputs of the
8 second spatial switching fabric associated with the
9 channel combiner that is associated with said each
10 amplifier.

1 27. An optical router according to claim 24, further
2 comprising:

3 a plurality of optical switches, one switch of the
4 plurality of switches per wavelength filter of the
5 plurality of wavelength filters, each switch of the
6 plurality of switches comprising an input, a first switch
7 output, and a second switch output, said each switch being
8 capable of receiving the bundle associated with the filter
9 that is associated with said each switch and selectively
10 transmitting the bundle associated with the filter that is
11 associated with said each switch to the first or the
12 second switch output of said each switch;

13 a redundant path channel combiner comprising an
14 output and inputs coupled to the second switch outputs of
15 the plurality of optical switches;

16 a redundant path wavelength filter capable of
17 separating one or more wavelength channels from one of the
18 bundles of wavelength channels;

19 a redundant path wavelength converter capable of
20 receiving a redundant path add channel and converting the
21 received redundant path add channel to a different
22 wavelength;

23 a redundant path multiplexing unit coupled to the
24 redundant path wavelength filter and to the redundant path
25 wavelength converter, the redundant path multiplexing unit
26 being capable of multiplexing at least a subset of
27 channels of the one of the bundles of wavelength channels
28 and the converted redundant path add channel;

29 wherein:

30 the plurality of channel combiners comprises a first
31 channel combiner, the first channel combiner being coupled
32 to the redundant path multiplexing unit; and

33 the first channel combiner is capable of multiplexing
34 the channels received by the first channel combiner from
35 the output of the first spatial switching fabric
36 corresponding to the first channel combiner, the channels
37 multiplexed by the multiplexing unit associated with the

38 first channel combiner, and the channels multiplexed by
39 the redundant path multiplexing unit.

1 28. An optical router according to claim 27, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a difference frequency mixer.

1 29. An optical router according to claim 28,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the difference frequency mixer of said each converter
7 of the plurality of wavelength converters comprises a
8 tunable pump source capable of producing pump output at
9 different wavelengths to enable said each converter to
10 convert the received add wavelength channel to different
11 transformed wavelengths.

1 30. An optical router according to claim 27, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a cross-gain modulator.

1 31. An optical router according to claim 30,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the cross-gain modulator of said each converter of
7 the plurality of wavelength converters comprises a tunable
8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 32. An optical router according to claim 27, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a cross-phase modulator.

1 33. An optical router according to claim 32,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the cross-phase modulator of said each converter of
7 the plurality of wavelength converters comprises a tunable

8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 34. An optical router according to claim 27, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a four-wave mixer.

1 35. An optical router according to claim 34,
2 wherein:

3 said each filter of the plurality of wavelength
4 filters comprises a tunable band pass filter capable of
5 separating different one or more wavelength channels; and

6 the four-wave mixer of said each converter of the
7 plurality of wavelength converters comprises a tunable
8 pump source capable of producing pump output at different
9 wavelengths to enable said each converter to convert the
10 received add wavelength channel to different transformed
11 wavelengths.

1 36. An optical router according to claim 1, wherein
2 said each filter of the plurality of wavelength filters
3 comprises a tunable band pass filter characterized by a

4 passband with an adjustable bandwidth and an adjustable
5 center wavelength, whereby said each filter of the
6 plurality of wavelength filters is capable of separating a
7 first wavelength channel of the one or more wavelength
8 channels at different wavelengths and with variable
9 channel separation.

1 37. An optical router according to claim 36, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a tunable pump source capable of
4 producing pump output at different wavelengths to enable
5 said each converter to convert the received add wavelength
6 channel to different transformed wavelengths.

1 38. An optical router for routing wavelength
2 channels received in bundles of wavelength channels, the
3 router comprising:

4 a plurality of wavelength filters, one filter of the
5 plurality of wavelength filters per bundle, each filter of
6 the plurality of wavelength filters being capable of
7 separating one or more wavelength channels from the bundle
8 associated with the filter;

9 a plurality of wavelength converters, one converter
10 of the plurality of wavelength converters per bundle, each
11 converter being capable of receiving an add wavelength
12 channel and converting the received add wavelength channel
13 to a transformed wavelength;

14 a first spatial switching fabric comprising a
15 plurality of inputs and a plurality of outputs, the inputs
16 of the first spatial switching fabric being coupled to the
17 plurality of wavelength filters to receive the separated
18 one or more wavelength channels;

19 a plurality of multiplexing units, one multiplexing
20 unit of the plurality of multiplexing units per bundle,
21 each multiplexing unit of the plurality of multiplexing
22 units being coupled to a respective output of the
23 plurality of outputs of the first spatial switching
24 fabric, said each multiplexing unit of the plurality of
25 multiplexing units being capable of multiplexing at least
26 a subset of channels of the bundle associated with said
27 each multiplexing unit, the add wavelength channel
28 converted by the converter associated with the bundle that
29 is associated with said each multiplexing unit, and
30 channels received from the respective output of the

31 plurality of outputs of the first spatial switching
32 fabric.

1 39. An optical router according to claim 38, wherein
2 said each filter of the plurality of wavelength filters
3 comprises a tunable band pass filter capable of being
4 adjusted to separate different one or more wavelength
5 channels.

1 40. An optical router according to claim 39, wherein
2 said each converter of the plurality of wavelength
3 converters comprises a tunable pump source capable of
4 producing pump output at different wavelengths to enable
5 said each converter to convert the received add wavelength
6 channel to different transformed wavelengths.

1 41. An optical router according to claim 38, wherein
2 said each multiplexing unit of the plurality of
3 multiplexing units comprises a fused fiber optical power
4 splitter.

1 42. An optical router according to claim 41, wherein
2 the fused fiber optical power splitter of said each
3 multiplexing unit of the plurality of multiplexing units

4 comprises active fiber filler capable of amplifying the
5 wavelength channels multiplexed by said each multiplexing
6 unit of the plurality of multiplexing units.

1 43. A router comprising:

2 a first wavelength selection module comprising an
3 input port capable of receiving a first plurality of
4 wavelength channels, a first wavelength filter capable of
5 separating a first separated channel from the first
6 plurality of wavelength channels, and a first pass-through
7 output port for outputting wavelength channels of the
8 first plurality of wavelength channels;

9 a second wavelength selection module comprising an
10 input port capable of receiving a second plurality of
11 wavelength channels, a second wavelength filter capable of
12 separating a second separated channel from the first
13 plurality of wavelength channels, and a second pass-
14 through output port for outputting wavelength channels of
15 the second plurality of wavelength channels;

16 a first wavelength conversion module comprising a
17 first wavelength converter capable of receiving a first
18 add channel at a first add wavelength and converting the
19 first add channel to a first converted wavelength, a first

20 multiplexing unit coupled to the first pass-through port
21 and to the first wavelength converter, the first
22 multiplexing unit being capable of multiplexing the
23 wavelength channels of the first plurality of wavelength
24 channels received from the first pass-through port and the
25 converted first add channel;

26 a second wavelength conversion module comprising a
27 second wavelength converter capable of receiving a second
28 add channel at a second add wavelength and converting the
29 second add channel to a second converted wavelength, a
30 second multiplexing unit coupled to the second pass-
31 through port and to the second wavelength converter, the
32 second multiplexing unit being capable of multiplexing the
33 wavelength channels of the second plurality of wavelength
34 channels received from the second pass-through port and
35 the converted second add channel;

36 a first spatial switching fabric comprising a first
37 input coupled to the first wavelength selection module to
38 receive the first separated channel, a second input
39 coupled to the second wavelength selection module to
40 receive the second separated channel, and a plurality of
41 outputs comprising a first output and a second output;

42 a first channel combiner coupled to the first output
43 of the plurality of outputs of the first spatial switching
44 fabric and to the first wavelength conversion module, the
45 first channel combiner being capable of receiving and
46 multiplexing wavelength channels from the first output of
47 the first spatial switching fabric and the channels
48 multiplexed by the first multiplexing unit; and

49 a second channel combiner coupled to the second
50 output of the plurality of outputs of the first spatial
51 switching fabric and to the second wavelength conversion
52 module, the second channel combiner being capable of
53 receiving and multiplexing wavelength channels from the
54 second output of the first spatial switching fabric and
55 the channels multiplexed by the second multiplexing unit.

1 44. A router according to claim 43, wherein:

2 the first wavelength filter comprises a first tunable
3 band pass filtering element capable of being adjusted to
4 separate the first separated channel in a range of
5 wavelengths; and

6 the second wavelength filter comprises a second
7 tunable band pass filtering element capable of being

8 adjusted to separate the second separated channel in a
9 range of wavelengths.

1 45. A router according to claim 44, wherein the
2 first wavelength converter comprises a tunable pump source
3 capable of producing pump output at different wavelengths
4 to enable said each converter to convert the first add
5 channel to a first converted wavelength in a range of
6 wavelengths.

1 46. An optical wavelength router comprising:
2 first wavelength selection means for receiving a
3 first plurality of wavelength channels from a first in
4 fiber, and for selectively separating at least a first
5 channel from the first plurality of wavelength channels;

6 second wavelength selection means for receiving a
7 second plurality of wavelength channels from a second in
8 fiber, and for selectively separating at least a second
9 channel from the second plurality of wavelength channels;

10 first wavelength conversion means for receiving a
11 first add wavelength channel at a first add wavelength and
12 converting the first add wavelength channel to a first
13 transformed wavelength;

14 second wavelength conversion means for receiving a
15 second add wavelength channel at a second add wavelength
16 and converting the second add wavelength channel to a
17 second transformed wavelength;

18 first wavelength multiplexing means coupled to the
19 first wavelength conversion means and to the first
20 wavelength selection means, the first wavelength
21 multiplexing means being for multiplexing at least a first
22 subset of wavelength channels of the first plurality of
23 wavelength channels and the converted first add wavelength
24 channel;

25 second wavelength multiplexing means coupled to the
26 second wavelength conversion means and to the second
27 wavelength selection means, the second wavelength
28 multiplexing means being for multiplexing at least a
29 second subset of wavelength channels of the second
30 plurality of wavelength channels and the converted second
31 add wavelength channel;

32 first spatial switching means comprising a first
33 input, a second input, a first output, and a second
34 output, the first spatial switching means being for
35 routing wavelength channels from the inputs of the first

36 spatial switching means to the outputs of the first
37 spatial switching means;

38 first channel combiner means for combining wavelength
39 channels appearing at the first output of the first
40 spatial switching means and the wavelength channels
41 multiplexed by the first wavelength multiplexing means;
42 and

43 second channel combiner means for combining
44 wavelength channels appearing at the second output of the
45 second spatial switching means and the wavelength channels
46 multiplexed by the second wavelength multiplexing means.

1 47. An optical wavelength router according to claim
2 46, wherein:

3 the first wavelength selection means comprises first
4 tunable band pass filter means capable of being adjusted
5 to separate the first channel in a range of wavelengths;
6 and

7 the second wavelength selection means comprises
8 second tunable band pass filter means capable of being
9 adjusted to separate the second channel in a range of
10 wavelengths.

1 48. An optical wavelength router according to claim
2 47, wherein the first wavelength conversion means
3 comprises a first tunable wavelength conversion means for
4 converting the first add wavelength channel to the first
5 transformed wavelength in a range of wavelengths.

1 49. An optical wavelength router according to claim
2 48, wherein the first tunable wavelength conversion means
3 comprises a difference frequency mixer means for
4 wavelength conversion.

1 50. An optical wavelength router according to claim
2 48, wherein the first tunable wavelength conversion means
3 comprises a cross-gain modulator means for wavelength
4 conversion.

1 51. An optical wavelength router according to claim
2 48, wherein the first tunable wavelength conversion means
3 comprises a cross-phase modulator means for wavelength
4 conversion.

1 52. An optical wavelength router according to claim
2 48, wherein the first tunable wavelength conversion means

3 comprises a four-wave mixer means for wavelength
4 conversion.

1 53. An optical wavelength router according to claim
2 48, further comprising second spatial switching means
3 comprising a first input, a second input, and a plurality
4 of outputs, the first input of the second spatial
5 switching means being coupled to the first channel
6 combiner means to receive the wavelength channels combined
7 by the first channel combiner means, the second input of
8 the second spatial switching means being coupled to the
9 second channel combiner means to receive the wavelength
10 channels combined by the second channel combiner means,
11 the second spatial switching means being for routing the
12 wavelength channels combined by the first and the second
13 channel combiner means from the first and second inputs of
14 the second spatial switching means to the plurality of
15 outputs of the second spatial switching means.

1 54. An optical wavelength router according to claim
2 53, further comprising means for providing router path
3 fault protection through redundancy.

1 55. An optical wavelength router according to claim
2 54, further comprising:

3 first means for amplifying wavelength channels
4 interposed between the first channel combiner means and
5 the first input of the second spatial switching means; and
6 second means for amplifying wavelength channels
7 interposed between the second channel combiner means and
8 the second input of the second spatial switching means.

1 56. An optical wavelength router according to claim
2 46, wherein:

3 the first wavelength selection means comprises first
4 tunable band pass filter means characterized by a first
5 adjustable center wavelength and a first adjustable
6 bandwidth; and

7 the second wavelength selection means comprises
8 second tunable band pass filter means characterized by a
9 second adjustable center wavelength and a second
10 adjustable bandwidth.

1 57. An optical wavelength router according to claim
2 56, wherein the first wavelength conversion means
3 comprises a first tunable wavelength conversion means for

- 4 converting the first add wavelength channel to the first
- 5 transformed wavelength in a range of wavelengths.